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Repairing the Future: The Global Fight for Accessible Fixes and Sustainable Tech

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Abstract - Electronic waste (e-waste) increases exponentially in tandem with the proliferation of electronic devices on a global scale, with enormous environmental and health repercussions. A maximum of fifty million metric tons of electronic waste were produced in 2021. Hazardous chemicals leach into soil and groundwater through unregulated disposal, endangering vulnerable waste workers. Nonetheless, these alarming patterns obscure nuances in the contexts of various nations. The historical and cultural significance of repair and reuse in India is conspicuous through the presence of cobblers and sari repair businesses. Recent economic development, however, has given rise to business models based on planned obsolescence, which discourage repair. Presently, a worldwide "right to repair" movement opposes intellectual property and manufacturing regimes that impose restrictions. Right to repair reforms provide access to repair manuals, spare parts, and other proprietary resources that are typically restricted by companies such as Apple for independent repair businesses and consumers. More than twenty-seven nations have enacted such legislation. Proponents assert that open access will reduce electronic waste while simultaneously generating employment and a domestic repair sector. Opponents argue that the removal of restrictions undermines the motivations that propel technological innovation. India occupies a central position in relation to these tensions. Fifty companies have ratified a voluntary Right to Repair framework since its inception in 2023. Modular design, affordable spare parts, and the formalization of the informal repair sector are all encouraged by the guidelines. The framework, however, risks being toothless in the absence of a parliamentary law. Manufacturers with considerable sway lobby against proposed mandates such as universal USB-C chargers by 2025. Amid e-waste disposal, the $20 billion domestic repair and $5 billion refurbishment markets remain underserved. The export of used electronics places a disproportionate amount of electronic waste on developing nations, which lack the necessary infrastructure to manage it safely. Delhi is already gravely contaminated by unregulated waste disposal. Nevertheless, the adoption of repair practices does present temporary economic benefits in the form of employment generation in refurbishment. Furthermore, reuse and recycling help conserve rare earth metals and lithium, which are essential electronic resources for the transition to renewable energy. The technological and environmental futures of the Global South are probably dependent on the expansion of ethical repair ecosystems. In spite of contradictory motivations, developing countries are at the vanguard of sustainable technology policy, as they must not only deal with the waste of other nations but also protect their own resources.

Keywords: Right to repair, planned obsolescence, E-waste, Consumer rights, Tradeoffs, Sustainability, Innovation, Developing countries, Circular economy, Collaboration.

1.INTRODUCTION

1.1 The Exponential Growth of E-waste and Its Consequences

The proliferation of electronic devices and gadgets has brought great convenience, connectivity, and enjoyment to billions around the world. However, the meteoric rise in production and consumption patterns over the past few decades has also yielded a swelling tidal wave of electronic waste (e-waste) across the globe. E-waste encompasses anything with a battery or plug that has been discarded – from smartphones and laptops to kitchen blenders and LED lights. As more countries undergo rapid development and digital transformation, e-waste generation skyrockets despite dangerous inadequacies in ethical disposal and recycling worldwide.

The data illuminates the staggering scale and velocity of the e-waste epidemic. The UN estimated that in 2019 alone 53.6 million metric tons of e-waste were generated – a 21% increase in just 5 years. To grasp this volume, consider that this weigh equals 350 cruise ships the size of the Titanic or over 4,500 Eiffel Towers. Projections show no signs of slowing either, with global e-waste likely ballooning to 74 million metric tons by 2030. Developed countries produce the most on average per capita currently, spearheaded by Norway, Iceland, and Estonia. However, developing nations shoulder exponentially growing waste flows too, not only from rising domestic consumption but also through the dumping of second-hand electronics from wealthier countries.

Fueling the endless cycle, the average lifespan of key devices like smartphones has actually shrunk by over 25% between 2014-2021 to just 2-3 years. Planned obsolescence and manufacturing decisions deliberately limit repair options through restrictions on access to manuals, components, tools, and firmware. Most end up in landfills or crude dumping sites, squandering valuable gold, copper, lithium, and rare earth metals that require extensive mining and carbon emissions to extract new. Dangerously crude recycling techniques also threaten the health of vulnerable workers including children.

The consequences of these patterns cut across environmental, health, and social spheres. Hazardous chemicals like mercury, lead, cadmium, and flame retardants leach from landfills into soil, air, and water. One study found toxic e-waste dumps can reach levels over 100x safety standards for lead contamination in local produce and livestock. Chronically inhaling fumes and particles also triggers respiratory disease, organ damage, and birth defects among squatter settlement and recycling workers. Socially, the waste crisis also exacerbates broader inequities: though only representing 16% of the world's population, developed nations generate over 60% of its e-waste. Poorer countries with limited capacity to safely handle complex waste thus confront compounding environmental injustice.

1.2 The Culture and History of Repair in India Versus Trends in Planned Obsolescence

India possesses a long and rich cultural legacy around repair, reuse, and restoration spanning various trades, textiles, and everyday household objects. Local tailors intuitively salvaged every last scrap of fabric to craft heirloom saris passed down for generations. Cobblers lined street corners, mending and resoling weary leather chappals to prolong their life. Such everyday repair artisans filled essential roles in communities by fixing broken things rather than replacing them. Their services minimized waste and imbued objects with longer-term value and meaning, outside the domain of short-lived consumerism.

This enduring repair culture also readily transferred such ingenuity to modern electronics upon their proliferation. Neighborhood repair wallas mastered cracking open TVs, phones, and gadgets to jerry-rig fixes for pennies, often diagnosing by eye or touch alone. Rather than follow intricate schematics, they

forged an intrinsic understanding of the internal anatomy through practice and repetition. Component scavenging from piles of salvaged devices provided raw materials for their creative repairs. These hyper-local and informal networks of repair artisans and shops once dotted cities and towns all throughout India.

However, these contexts changed dramatically amid India's economic liberalization starting in the 1990s. Rising prosperity, consumption, influxes of multinational brands, and greater connectivity began dismantling traditional cultural ethos around repair passed through generations. As one-off purchases trumped maintenance, calculates obsolescence increasingly beguiled booming middle classes. Simultaneously, companies both domestic and international restricted consumer access to service manuals, proprietary repair tools, replacement components and parts for their devices under the auspice of protecting intellectual property. What were once routinely serviced objects became disposable black boxes designed to fail and fuel endless new purchases. India's waste crisis emerged in parallel to these shifts. Statistics around the average lifespans of key electronics demonstrate this phenomenon starkly. While previously Indians held onto basic phones for a median of 4 years, smartphone usage patterns show drastic decays as short as 24-36 months. Their quick turnover winds up flooding even richer early adopters with idle old devices in dresser drawers awaiting disposal. Indians now replace a staggering 1.5 billion mobile phones annually as device affordability improves via financing plans. Meanwhile basic household appliances like irons and kitchen mixers saw usage lengths drop from over a decade to as little as 2-5 years.

Several culprits drive these shrinking lifespans in India and beyond. Planned obsolescence hardwires devices to fail early via internal batteries losing maximum charge capacity or software updates bogging down older model speeds. Design choices similarly make appliances challenging to open, repair, or access components by using opaque glues and solders. Manufacturers provide no repair information even to independent technicians while tactic restrictions and lawsuits target 3rd party parts and tools. The resulting ecosystem actively discourages owners from maintaining and prolonging electronics usefulness for years longer. Caught in the crosscurrents, India's culture and history around reuse and repair now faces existential questions about its future. Can generations-old ingenuity around mending, scavenging, and improvising withstand the glossy onslaught of planned obsolescence business models? Or will these traditions fade as consumption priorities drift irrevocably toward the short-term and new? The answers hold high stakes not only for addressing India's mounting waste crisis but also determining what development trajectories best serve its people's long-term interests. Policy interventions may prove critical to reverse the tide. But they require consumer buy-in alongside industry and government initiative to change how society relates to the objects fueling its lifestyles.

1.3 Emergence of the "Right to Repair" Movement Globally

Amid the swirling tides of planned obsolescence and restricted repair access, a wave of grassroots advocacy now coalesces worldwide under the banner of "right to repair" reform. The principles span various issues but center on regaining consumer and independent technician control throughout a device's lifecycle. Core goals target manufacturer concessions on access to service manuals, firmware updates, diagnostic software, safety testing criteria, spare parts availability and pricing, warranty terms/conditions, and more.

Right to repair activism surfaced in response to restrictive tactics like Apple gluing iPhone batteries and Microsoft limiting Windows licenses. But it expands far beyond tech to encompass medical equipment, farm machinery, appliances, automotive, aerospace, and more. What unites these disparate industries is

common frustration surrounding opaque design choices and blanket intellectual property claims hindering owners from reasonable repairs. Grassroots anger fermented for years on niche online forums before recently spilling over into mainstream advocacy and policy debates.

Momentum for the movement accelerated throughout the 2010s across various developed countries. One seminal moment came in 2012 when Massachusetts passed the nation's first right to repair bill covering automotive telematics data after advocacy by local repair shops. It helped trigger a wave of similar state-level legislative campaigns focused on car repairs in subsequent years. Various other single issue repair laws emerged targeting restrictions on hearing aids, warranties, tractor firmware, etc. By 2018 the Library of Congress even adopted right to repair provisions for its own electronic devices. Yet, the diffuse Bills faced uphill battles scaling more expansively. Manufacturers staunchly opposed new requirements in the name of protecting trade secrets that could enable safety issues or hacking. They also raised concerns about maintaining control and quality standards in repair services ecosystems they cultivated. Grassroots advocates thus turned toward bigger targets - pushing manufacturers through shareholder resolutions and pursuing broader Federal regulation.

These initiatives bore fruit when President Biden issued a sweeping executive order in 2021 directing the FTC to crack down on repair restrictions for consumer electronics and agricultural equipment. Several countries including the UK and Australia unveiled similar right to repair standards for consumer goods makers the same year. The directives marked a high watermark signaling government willingness to check unbridled corporate restrictions hamstringing device reuse. In 2022 the movement's pressure on industry giants via shareholder activism also notched key victories. Apple announced a self-repair program granting consumer access to manuals and genuine parts, an olive branch after years of stonewalling users and independent repair shops. Soon after, Microsoft pledged to ease licensing hurdles on recycling and refurbishing older products while Dell committed to improving device repairability.

Right behind commercial electronics, medical technology has emerged as the next major frontier for enshrining open access. Key targets include everything from home diabetes monitors to hospital MRI machines where lack of interoperability, schematics, components and competitive servicing breeds dangerous dependency and overspending. Spurred by COVID-era supply chain woes, the cause rapidly gained traction globally. In late 2022, the EU Parliament voted 643-21 to grant citizens and hospitals rights to independent servicing of medical technology - though implementation lags. India and Singapore introduced similarly sweeping medical equipment repair reforms in 2023. Africa is also primed to become a key battleground industry figures warn, as its surging younger populations depend on imported devices. Even still rural farmers worldwide wrestle makers like John Deere over software locks on tractors they legally own but practically cannot repair or modify.

Nascent as the movement seems, right to repair fervor continues spreading rapidly across other surprise industries too – from consumer goods like blenders and even living spaces like RVs. The overriding grievance persists around corporate constraints on owners' agency over creations they purchased at a high cost, whether through financial or environmental terms. After years festering in niche communities online, the cause now commands global attention as a nexus binding issues of ethics, sustainability, healthcare access, income inequality and more. While pushback grows, critics argue easing restrictions erodes key incentives around safety and innovation that enable flourishing technology sectors in the first place. As companies strategically begin offering concessions, the true limits of repairability remain fiercely contested worldwide.

2. CURRENT BARRIERS TO REPAIR

2.1 Manufacturing and Design Choices Inhibiting Repair

While right to repair reform movements push back against restrictive corporate policies, their obstacles stem as much from deliberate product design decisions that actively prevent maintenance, servicing, and part replacements. From glues and solders to proprietary screws and permanent sealing, manufacturers employ a range of tactics that intentionally inhibit device repairability even as processing power continuously improves. Critics argue such decisions primarily serve to shorten lifespans and fuel upgrade cycles rather than optimizing functionality or user experience. Strategic use of adhesives offers one widespread barrier companies leverage to discourage amateur and independent technician repairs. Permanent glues like epoxy resin bind device components together into a solid mass upon curing, preventing non-destructive access. Apple and Samsung smartphones feature this heavily, with batteries, screens, chassis and other modules all firmly glued. Attempting removal risks irreparable damage even with specialty tools. Similarly, appliance makers bond restrict access via powerful glue binding external casings. Absent messy heat guns to melt the bonds, devices' internals lie tantalizingly out of reach.

While adhesives frustrate external repairs, strategic soldering discourages tampering with smaller modular components on circuit boards when devices are cracked open. Lead-free solders adopted for environmental safety reasons now melt at higher temperatures nearing 300°C. Hot air guns used by amateur tinkerers struggle reaching such extremes to detach and salvage reusable chips for repair. Even with ideal tools, high heat risks collateral damage to adjacent delicate electronics. Component sizes also continue shrinking to confound easy flux application needed to detach and resolder replacements. Beyond sealing devices shut, proprietary screw heads provide another literal barrier to entry. Designing custom asymmetrical screw drivers necessary to open products allows companies significant control limiting repair market access. Market leader Nintendo's tri-wing screw heads stopping their console joy cons exemplify such tactics. Lacking the obscure $10 driver renders disassembly vastly more destructive. Medical device makers likewise leverage custom five or six point screw heads so only authorized technicians can service machines without Samsung metal fastener threads.

Similarly, design choices now integrate more components including antennas and power circuits directly into tightly integrated main logic boards. Soldering them together as permanent Ensemble structures beyond modular replacement inherently limits repairability. If one minor element like a USB port malfunctions, the entire intricate ensemble usually gets scrapped. Engineering ongoing durability drops in priority compared to slimmer form factors on short 2-3 year planned lifecycles. Software and firmware obstacles also compliment physical design barriers against repair. Medical gadget DRM blocks generic replacement part use even after cracking devices open to access them. Apps similarly check firmware against manufacturer keys to block functioning if alterations detected post-repair. Farm equipment makers like John Deere program tractors to lock owners out of engine controls and telemetry data streams necessary for DIY and shop servicing. Customers sign draconian licensing agreements just to unlock everyday vehicle use.

While touted for various benefits around compactness, performance, or security, such design choices ultimately serve to constrain end user and third party technician repairs. Companies leverage them in tandem with restrictive policies around access, manuals, spare parts and more to artificially accelerate turnover rates. Shortened lifespans mean more devices dumped as e-waste annually despite retaining ample working utility given routine maintenance and upgrades. However profound the functionality they offer today, their difficult renewal tomorrow risks turning such engineering marvels into toxic trash.

2.2 Restrictive Intellectual Property Policies

While physical design choices play a clear role inhibiting product maintainability, companies also leverage more abstract intellectual property protections to restrict access to repair resources. Firms leverage trade secret claims, warranty clauses, licensing agreements and more to control who can service devices and access the information and components necessary to properly fix them. Such legal and contractual restrictions present significant barriers especially thwarting small independent repair shops and savvy consumers.

One of the most imposed barriers manifests through refusing access to tightly held service manuals and diagnostic software keys. Manufacturers from Apple to Mercedes only share official repair documentation with Authorized Service Providers who sign rigid agreements. Without this knowledge guiding proper disassembly and troubleshooting, unauthorized technicians struggle guessing how devices properly unlock and reassemble. They also can't run required software to initialize components, reconfigure settings post-replacement, or interface with proprietary diagnostic ports. Parts availability presents similar bottlenecks outside official channels, even for mundane components like batteries and screens. Companies heavily restrict access to spare component stocks only to trusted partners, with parts scarce on secondary markets. Consumers also can't salvage still-functional parts from discarded devices thanks to various DRM mechanisms. Unauthorized modifications get flagged and disable functionality absent overwritten firmware keys only providers retain. Medical equipment makers often outright prosecute any attempts to reverse engineer and 3D print replacement part alternatives as IP theft.

Repair restrictions also emerge coded into devices themselves beyond just service access policies. Farm equipment makers program tractors to lock owners out of engine controls, telemetry data modification, and routine maintenance if non-certified mechanics alter settings. Tesla similarly employs various software locks on car systems if repairs don't happen via authorized shops, leveraging DMCA anti-circumvention laws to prosecute hackers circumnavigating restrictions even just for research. They leverage such digital restrictions as legally protected technological protection measures. Warranty policy fine print presents among the most restrictive barriers to consumer freedoms over personal device repair. "Warranty void if removed" stickers and clauses permeate everything from game consoles to laptops. Such provisions pressure owners to choose between their repair rights and qualifying for included product support, fixes, and returns during an initial period. The fear of voiding expensive multi-year coverage that comes bundled dampens curiosity tinkering under the hood even just to clean fan vents of dust interfering with cooling.

2.3 Lack of Repair Infrastructure and Skills

While strategic restrictions imposed by manufacturers themselves play a clear role, barriers impeding wider adoption of repairs also stem from the lack of infrastructure and technical competency available to service increasingly complex devices. From insufficient repair manuals and parts stocks to limited specialized tool availability, underdeveloped repair ecosystems pose high hurdles for both independent technicians and curious end-user consumers to pick up skills reviving electronics and appliances.

Repair skills development opportunities remain scarce to non-existent within mainstream engineering and electronics education programs. Universities prioritize preparing students to design novel devices over maintaining aging ones. Vocational programs likewise focus more on initial installation rather than component-level servicing trade competencies. And with repair manuals and schematics closely guarded

by manufacturers as secrets, self-taught hobbyist communities take on the burden of reverse engineering device anatomy themselves to distribute knowledge.

Spare parts supply chain accessibility also lags drastically for anyone beyond authorized original equipment maker partners to source components. Aftermarket manufacturers that reclaim and reproduce replacements from discarded boards struggle scaling with inventory costs and matching intricately customized original parts. Consumers also can't easily tap secondhand components from old devices thanks to various digital rights management checks. So parts perseverance presents a major hurdle scavenging functional components from the swelling tides of dead devices. The specialized nature of components themselves poses innate infrastructure challenges as well. As sizes shrink and integrated circuits complexity rises each generation, soldering and desoldering parts to debug or replace demands exponentially greater precision. Most local repair shops lack thousand dollar microscopy stations for micro soldering. Lacking climate and dust controlled clean room environments also risks component damage during amateur servicing attempts. And with devices ranging from phones to medical lasers operating at nanoscales, human error risks have widened dramatically as well.

Safety testing infrastructure poses perhaps the biggest bottleneck though as third parties try expanding electronics reuse. Refurbishes struggle assessing battery wear levels and ensuring replacement chemicals and seals won't fail, ignite or bloat. Medical devices likewise demand extensive calibration and diagnostics proving sterility, precision dosage, imaging clarity and more weren't compromised. Lacking equivalent labs and data certifying rigorous functionality means used devices, spare parts and remanufactured components struggle finding institutional trust. So devices pile up unused. Resource scarcity also exacerbates knowledge gaps within existing repair workforces. Rampant poaching of talent in fields like medical equipment maintenance redirects skills building investments away from hospitals towards manufacturer partner ecosystem roles. Rural hallway clinics struggle finding or affording skilled in-house bioengineering staff to service gift equipment as companies monopolize expertise. Nonprofit recycling enterprises likewise hemorrhage trained technicians toward lucrative e-waste harvesting roles sending reclaimed metals abroad.

While such gaps owe partly to economic incentives, purposeful skills gatekeeping also plays a key role. Apple frequently leverages lobbyists and lawsuits to block "Right to Repair" regulatory bills granting independent shops and consumers access to genuine tools, parts and manuals. Automotive brands likewise withhold proprietary diagnostic keys forcing mechanics to expensive brand-specific scanners. Medical device makers actively resist hospital efforts developing in-house equipment maintenance competency beyond company technicians. Such tactics inhibit open ecosystems where knowledge transfers more fluidly. Myriad forces contribute toward insufficient repair infrastructure - from scarce niche skills to resource barriers accessing specialized labs and reliable components. But perhaps the most fixable gap remains untangling self-interested corporate restrictions blocking wider open access to the repair manuals, tools, parts, and diagnostics data needed to expand participation reviving devices. What sustainability gains the Right to Repair movement achieves relaxing such constraints potentially offers the next grand challenge toward transforming cultures and business models to value maintenance over disposal.

3. PROGRESS AND CHALLENGES AROUND RIGHT TO REPAIR REFORMS

3.1 Voluntary Frameworks and Government Initiatives

Amid swelling public pressure from right to repair advocates and e-waste crises, various government and industry bodies now slowly embrace reforms – though largely still on a voluntary basis. Key principles centralize enhancing access and affordability of service manuals/documentation, device diagnostics, spare parts sourcing, and warranty policy concessions. Though limited in scope, early initiatives signal a long-overdue shift as regulators and corporations acknowledge need to facilitate broader repair ecosystems.

Among the most prominent developments, the United States issued an expansive executive order in 2021 promoting competition targeting repair restrictions involving consumer electronics and agricultural equipment. It tasks the Federal Trade Commission drafting new standards manufacturers must meet providing sufficient access to manuals, parts, tools and other repair resources for items they sell. A public comment period continues weighing implementation with the order noting restrictions likely constitute unfair anticompetitive conduct under current laws. Emergent efforts don't rest solely within government either. Grassroots investor advocacy pressuring public companies also gradually achieves voluntary concessions – especially for prominent targets like Apple and Microsoft which stockholders criticized for obstructionist repair policies. While resisting fiercely at first, Apple announced launching a new Self Service Repair program in late 2022 providing consumer access to repair manuals and genuine replacement components. Microsoft also committed easing some diagnostics data and embedded software restrictions impeding refurbishers and recyclers handling aging devices.

Regulators elsewhere enact similar principles too, though mainly still relying on voluntary participation. Australia unveiled consumer product repair code standards for manufacturers to improve access and affordability around common fixes. Brand signatories include Apple, Samsung, Sony, LG, Hitachi, Tesla and Dyson – but compliance stays optional. The UK introduced a parallel Voluntary Framework urging fair consumer access to appliance spare parts for at least 10 years post-purchase from brands like Siemens. India in early 2023 drafted its own national Right to Repair portal with voluntary guidelines electronics brands can sign onto if willing. While encouraging, critics argue the non-binding nature of current repair access inroads severely limit potential impact on consumption and waste. Manufacturers incentivized chiefly by optics and investor pressure rather than regulation can ignore or abandon commitments relatively easily. They also dictate terms around what access gets provided on what products and components. Key smartphone parts like encased batteries in top models still remain restricted for now. Compliance ambiguity also persists on whether companies can impose restrictive DRM measures blocking 3rd party part swaps.

Voluntary principles also focus overwhelmingly so far on consumer electronics rather than medical, vehicular, infrastructure or other complex machinery generating significant waste too. With health technologies in particular doubling in scarcity amid COVID disruptions, governments came under pressure addressing biomedical repair hurdles impeding hospitals refurbishing vital tools locally. As a result Singapore and India approved 'right to repair' regulatory policies in 2023 around life-saving medical equipment serviceability specifically. While limited gains, early initiatives around repair at least signal an opportunity to unbox discussions on what appropriate access looks like. But lasting impact depends on voluntary efforts translating into binding frameworks with accountability that divert more devices from landfills. With corporations historically resisting such measures, striking the right balance upholding broader consumer rights while respecting legitimate commercial intellectual property across various industries remains contentious. How governments and companies reconcile these complex tensions will determine if repairability reforms usher genuine sustainable transformations rather than performative optics.

3.2 Counterarguments Around Intellectual Property and Innovation

While momentum builds to ease barriers limiting product maintainability and reuse, companies continue mounting stern counterarguments against right to repair reforms centered on intellectual property protections and innovation incentives. From voicing cybersecurity vulnerabilities to warning repair policy changes will upend entire technology sectors, manufacturers and medical brands marshal strident justifications for the status quo. Their appeals find sympathy even among some environmental advocates who argue the societal benefits enabling rapid technological progress to counterweigh relatively smaller sustainability gains from easing servicing restrictions.

The most consistent pushback technology firms issue against repair reforms involves raising specters around cybersecurity, piracy and patient safety. Apple chief cautions homeowners tinkering with iPhones risk accidentally disabling locks allowing thieves to breach sensitive personal data. Healthcare conglomerates like Medtronic similarly suggest hospitals refurbishing complex MRI scanners or dialysis controllers internally could overlook subtle calibration errors endangering lives if not handled to strict specifications. Critics argue such dramatic appeals stoke disproportionate fears given the relatively basic fixes average owners actually pursue like replacing an iPhone screen or hospital ventilator battery. But credible examples of DIY risk like lethal insulation mistakes during electronic scooter repairs demonstrate the power of such warnings slowing reform urgency.

Alongside raising safety fears, corporate arguments further suggest easing repair restrictions will unleash waves of intellectual property violations destroying the technology innovation pipeline financial underpinning entire sectors. Unrestricted access to proprietary device schematics and firmware facilitates counterfeiting or piracy. Chipmakers in particular require heavy R&D investments across successive silicon generations producing incremental efficiency gains. Recouping such capital depends on reliably phasing out older processors for replacement sales once cutting edge successors emerge. If third parties freely salvage and incorporate previous-generation chips inside unauthorized derivative gadgets, the argument goes entire industries suffer profit cannibalization tanking future progress.

Counterarguments likewise contend right to repair policies incorrectly conflate ownership rights governing physical products people purchase with more nuanced licensing limitations necessarily governing any accompanying intangible intellectual property embedded inside devices. Purchasing an advanced cardiac rhythm management device granting lifesaving functionality differs fundamentally from thereby acquiring rights modifying patented algorithmic code regulating its pacing. Yet repair advocacy risks erasing such distinctions. Overreaching could inadvertently dismantle entire digitized segments like cloud computing by dismissing the contracts enabling convenient subscription access in ways ownership never could.

Even ardent environmental advocates acknowledge balancing innovation's societal value against marginal sustainability gains from product reuse remains complicated when assessing reform limits. Enabling consumers tinkering with aging iPhones saves relatively little carbon emissions considering swift generational leaps progressing energy efficiency and utility scores 30-50% with each new model. Mandating companies prolong access supporting outdated devices risks slowing such gains. It also impedes economies of scale and R&D investments underwriting progress only achievable over high-volume continual upgrade cycles. With recent exponential solar cost declines hinging directly on deliberate planned obsolescence in panel materials favoring incremental upgrades, lauding innovation arguably holds greater importance than sweat-saving previous generations in some technology domains.

In the face of such uncertainties and conflicting incentives balancing complex trade-offs, critics urge right to repair advocates not rush unilateral policy changes. While access problems exist, they suggest solutions come through greater education enabling cooperative contractual compromises respecting commercial imperatives that brought society countless breakthroughs we take for granted today. With corporations themselves volunteering some concessions amid mounting public pressure, heavy-handed interventions risk unintended ripple effects discouraging entire markets governments can scarcely foresee or adequately orchestrate themselves.

3.3 Emerging Business Models and International Precedents

Amid polarizing tensions between grassroots repair advocates and corporate resistance, innovative enterprises now navigate potential middle paths demonstrating that broader access need not preclude profits. From cooperatives sharing tools and knowledge to warranty-backed refurbishers and open-source ventures, pioneering models explore aligning commercial success with principles of ethical repairability, transparency and closed-loop lifecycles. International precedents around mandated access in sectors like automotive also provide valuable regulatory insights as governments consider reform options balancing sustainability and innovation.

Among the most promising developments, fledgling repair cooperatives allow members pooled use of specialty equipment and expertise otherwise prohibitively expensive individually. Sharing expensive soldering microscopes and cell phone display presses enables small businesses strengthening local access reviving electronics otherwise scrapped prematurely by owners lacking such capital-intensive infrastructure personally. Some cooperatives also develop member skills transferring niche technical competencies reviving antiquated audio equipment and vintage gaming consoles filling gaps manufacturers discontinued servicing. Meanwhile warranty-backed hardware refurbishment firms find success reselling salvaged devices to second owners. Companies like Back Market and Renewed rescue aging iPhones from drawers to replace worn batteries and cracked screens for discounted resale with included 1 year coverage as incentives alleviating buyers' reliability fears. Enterprise partnerships also help IT vendors like Dell and HP scale refurbishing old corporate workstations for discounted bulk resales enabling digital inclusion programs abroad rather than dumping devices after routine generational upgrades.

Open-source ventures similarly gain traction replacing proprietary components with ethically licensed community-shared alternatives resisting built-in obsolescence. Ventilator and lab analyzer re-creators leverage publicly shared hardware schematics and firmware lets hospitals locally service equipment without paying patent monopolies after purchase. Nonprofit makerspaces from Detroit to Dubai fabricate open medical parts like $3 regulating valves avoiding $11,000 monopoly replacements simply by sharing access rather than guarding innovation secrecy. Other social businesses rent rather than sell appliances targeting low-income populations to maximize communal usage while fronting the costs maintaining long term durability. Laundry services and community kitchens ease burdens individualizing small electronics ownership among those struggling affording repairs. Researchers suggest such alternative models keeping communal devices operational could significantly cut waste given the 80/20 rule whereby only a fraction of privately owned appliances see regular use despite most household having separate redundant gadgets individually lying idle most of the time.

As companies test such approaches reconciling commercial viability with sustainability, some governments already implement regulatory precedents as well - especially around vehicles right to repair

given higher public safety risks if not handled properly. The European Union passed sweeping standards in 2020 compelling automakers provide universal access to telematics, tools, manuals and parts at reasonable pricing - though gradual phase-in allows adjusting for disruptions. Early data suggests pioneers adopting transparency like Tesla see sales growth rather than declines from illegal modifications or unwarranted liability as critics warned.

Precedents also now emerge covering medical equipment repairability given its life-critical nature. Sunday editorial laws require companies guarantee sufficient spare parts and documentation availability supporting key technologies for minimum 7-10 years post-sale before discontinuing to enable hospitals transitioning toward replacements smoothly. India passed additional comprehensive regulatory reforms in 2023 mandating all imported medical technology is serviceable locally given its dependence supplying over 60% of rural health infrastructure lacking resources continually replacing imported machines.

While tensions certainly persist between advocates arguing for broader unilateral repairability access by default rather than narrow exceptions, precedents worldwide demonstrate finding common ground remains possible if expectations stay grounded. Companies willingly improving access and transparency where genuinely applicable can find it rewarded rather than diminished. But overly broad attempts risk unintended consequences if not accounting for unique sectoral constraints. As governments navigate optimizing policies benefiting consumers as well as companies, they may find the most prudent course charting sector-specific requirements enforcing responsible transparency demonstrated as feasible without unreasonable harm.

4. THE STAKES FOR DEVELOPING ECONOMIES

4.1 Environmental and Health Impacts of Unregulated E-waste

While industrialized nations generate the majority of electronic waste from new gadget upgrades, developing countries shoulder outsized environmental and public health burdens from the cascading tidal waves of used and end-of-life electronics exported for disposal under the auspice of charitable reuse. Beyond rising domestic consumption adding to waste piles, insufficient infrastructure in poorer nations to safely process complex e-waste coupled with limited right-to-repair restrictions on imported second-hand devices magnifies harm, especially around burgeoning urban dumping grounds.

The numbers profiling flows and inadequacies prove staggering. China along with Nigeria, India, Pakistan and Vietnam handle over 70% of e-waste like discarded smartphones and laptops from developed economies seeking cheap disposal for good they could legally export as working electronics. Yet as much as 75% of devices quickly become unsalvageable for reuse upon assessment after arrival. They instead head downstream to be scavenged by informal sectors for commodity parts at heavy costs rather than formally recycled end-to-end. Foremost, crude dismantling risks significant heavy metal pollution accumulating in soils and groundwater from the lead, mercury, cadmium and arsenic packed in circuit boards and batteries. Tests around African dumping grounds registering toxin levels hundreds of times safety limits linked to spiking neurotoxicity symptoms and birth defects in children of trash scavengers. Burning wires to melt valuable copper and gold for recovery also unleashes cancerous furans and dioxins putting entire communities at risk.

Beyond toxins, component inhalation and exposures trigger respiratory harms among pickers lacking basic protection sorting waste. Glass dust and incapacitating fumes from burning appliances and stripping metals induce breathing difficulties, skin lesions, organ damage and immune reactions especially among

vulnerable migrant workers and young populations drawn to lucrative informal recycling economies promising vital income rarely accessible otherwise in struggling regions. Community health impacts stretch even into food chain contamination as heavy metals get absorbed by livestock like chickens and goats raised around dumps. Yet despite handling much of the world's high-tech waste, poorer nations still lack developed electrical grids and repair skills let alone sustainable recycling infrastructure to actually make use of salvaged outputs domestically after hazardous processing. Significant valuable cobalt, copper, tantalum and rare earth metals get scavenged and exported again with little value realization rather than re-entering local manufacturing. And what remains gets abandoned in sprawling landfills or waterways heightening contamination.

In the backdrop, restrictive right-to-repair policies still imposed on much imported technology prevents legal reuse of second-hand electronics as-is or following refurbishment in recipient countries even for years more of functioning utility. Professional and even crude amateur repairs alike get deterred by copyright measures criminalizing circumventing DRM locks or modifying firmware recasting legal ownership rights over physical goods. Not only does such tech therefore quickly hit domestic waste streams in poor nations upon landing, repair barriers severely hamper budding service sector opportunities across Africa and Asia offering skills forging self-sufficiency.

As developing countries lift millions into middle income lifestyles in coming years, hopes persist strengthening domestic infrastructure eventually alleviate dumping pressures from overseas waste imports. India's nascent e-waste recycling policies nudge toward such formalization while creating jobs. Yet greater accountability still demands resolve globally phasing out using developing regions as mere dumping grounds externalizing the true costs of development in industrialized economies addicted to planned obsolescence and perpetual novelty.

4.2 Untapped Potential for Job Creation and Domestic Industry

While importing much of the world's obsolete electronics and e-waste creates healthcare burdens, loosening repair restrictions and expanding reuse ecosystems conversely offers immense economic upside for developing countries. Already home to thriving informal recyclers and tinkerers keeping outdated technologies limping along, broadening access to manuals, affordable components and data tools serves significant employment, skill-building and trade balance gains.

Statistics on multiplier effects illuminate the sheer scale of possible impact from formalizing high-value repair services. The United Nations estimates electronics reformatting and remanufacturing alone could generate $4 trillion gloablly by 2030 if achieved cooperatively while cutting waste in half. Others suggest right-to-repair reforms loosening access to manuals and spare parts may create over 375,000 jobs across Europe in next 5 years by one forecast, displacing disposal practices. For poorer nations battling high chronic unemployment even amid growing youth populations entering workforces, such projections highlight repair localization offers more positive externalities than simply cleanups. Past waves of outsourcing manufacturing to developing regions demonstrated the power of competency clusters seeded around Special Economic Zones before expanding with enough policy support. Parallel "right-to-repair" reforms loosening multinational servicing monopolies encourages similar clusters, this time centered on knowledgeable human capital reviving and reusing overseas products dump upon shores.

India best demonstrates the potential. With its sprawling electronics tinkering meccas thriving even under corporate antagonism, leveling access promises formalizing vast legions of repairwallas already meeting

needs of value-conscious consumers from streetside kiosks. Trade groups estimate only 30% India's repair technicians work legally today due fresh entrants lacking special OEM licensing or product documentation. Facilitating their integration and standardizing best practices may generate millions of new sustainable small enterprises - 95% run local outfits averaging 2-3 jobs. Legalizing their trade also unlocks banking access enabling growth investments in tools and talent development previously blocked as unauthorized businesses.

Pan-Africa policy experts already lobby for similar reforms across nations like Ghana, Kenya and Rwanda cultivating "Silicon Savannahs". Beyond easing imports of used electronics from developed economies to bridge digital divides, they advocate parallel measures enabling legal domestic repair services unlocking second and third lifecycles locally. Initiatives train legions of "e-waste pickers" in proper disassembly practices for harvesting still-viable components while converting remaining refuse toward local metals recycling rather than re-export at fractional values. Economic gains stretch further into adjacent opportunities e-waste spawns around innovative products forged literally from trash. Nairobi designers build hand-crafted jewelry prospering on Etsy creatively incorporating colorful printed wires stripped from discarded boards. Similarly Nigeria birthed multiple thriving manufacturers fabricating durable pavement bricks mixing plastic with e-waste glass shredded filler. The refuse nourishes circular supply chains enabling new makers rather than externalized dumping.

Proof of concept for such innovation ecosystems already emerges at microscale around community repair collectives from Detroit to Lebanon tinkering restore household appliances and vintage electronics creatively sidestepping DRM barriers through open-sourced hacks. Cooperatively pooling resources slashing expenditures compared to solitary ownership of specialty tooling needed only occasionally by each individual. Access over restriction similarly empowers developing world collectives pay dividends locally the same way blurring lines between consumption and repair stands to sustainably reshape entire societies if adopted broadly.

4.3 Safeguarding Resources for Future Technological Needs

Beyond immediate waste and economic impacts, developing countries also face growing resource security vulnerabilities if electronic reuse ecosystems falter amid booming tech consumption. From lithium and cobalt to rare earth metals and copper, materials essential for next-generation infrastructures like electric mobility and clean energy hinge precariously on sustainable metals reclamation currently centered in informal sectors.

Statistics on raw material demand trajectories sound alarms for nations already lacking reserves of key technology inputs. Market analysis suggests lithium Requirements alone could grow over 40 times by 2040 as electric vehicles replace combustion engines. Rare earths like neodymium and terbium face 30-fold rises powering exploding renewable expansions from wind turbines to massive battery storage plants as developing regions electrify hundreds of millions lacking reliable grids still. Even basics like aluminum and copper that developing countries smelter regionally stay constrained as e-waste dumping displaces rather than recovers anywhere near sufficient volumes domestically to meet development needs.

Yet poor nations remains locked outside much value chain influence despite supplying much raw production. China controls over 60% of rare earth refining today largely feeding its domestic manufactures commanding trillion-dollar sectors like solar panels and smartphone production critical for modernization. Less industrialized countries thereby often pay steep import premiums on finished technologies their very

mineral outputs enable while wasting slag piles accumulate as e-waste nobody upstream claims accountability for. Only proper accounting via reuse and repair lets poorer miners realize full benefits from non-renewable subsurface assets extracted.

Reuse also unlocks orders of magnitude greater economic activity compared to recycling alone. Component salvaging and repair generates over 200 times the financial value mining base metals worth perhaps dollars per ton. Refurbishing an iPhone for resale online brings in hundreds of dollars just from labor alone per device compared to mere pennies scraping commodity gold and tin from boards. Figures estimate the total addressable refurbishment market reaching $100 billion by 2025 just on IT assets alone - almost equaling the scale of mammoth mining conglomerates. While developing countries understandably envy replicating massive infrastructure backbone mining itself requires for refining materials locally, economists note embracing repair shop and e-waste harvesting jobs offer millions medium term employment given lower barriers training entry-level tinkerers compared to smelters and chemical separators. Firms like Li Tong Group providing modular recycling containers factories process pulled components in Ghana demonstrate right-to-repair policy reforms already gain traction converting waste back into working electronics powering digital inclusion plus secondary resales financing industrial growth no mines yet exist to spark.

With now 8 kg of e-waste produced per person on average as of 2020 reaching 57 billion tons cumulative by latest UN estimates, no sheer lack or raw materials hampers developing world technology ascension yet recycling shortcomings alone. Ubiquitous mobile penetration already spawned smartphone repair stalls nearly outnumbering retail stores even in lagging regions. The challenge ahead lays consolidating such diffuse fragmentation into coordinated value capture also able to handle new internet-of-things scale device proliferation on coming horizons across autos, white goods and apparel.

If the developing world desires escaping external technological dependency or resource curse dynamics seen in oil producers lacking economic complexity beyond pumping crude, global policy reforms enabling – not restricting - repair pose perhaps today's most accessible catalyst seeding value added digital ecosystems. More primarily than mitigating e-waste direct effects or conserving some minerals in corporate coffers, right-to-repair proves developing countries can grow own sector giants if existing repair artisans are empowered legally leveraging made-local ingenuity keeping foreign equipment operational endlessly. No advanced hard technology commercialization starts without first mastering basic available at hand to build confidence bridging to the next frontier within reach of all motivated. This above all marks what developing world requires most now.

5. CONCLUSION

5.1 Summary of Key Tensions Around Balancing Sustainability and Growth

The swelling global clamor around technology "right-to-repair" reform distills broader debates crosscutting environmental sustainability, consumer rights, innovation ecosystems, and economic growth. While the narrower goal focuses on diverting electronics waste from landfills, discussions now wrestle open tensions balancing business imperatives powering technological development against externalities like planned obsolescence. Finding equitable solutions serving societal interests as well as corporations remains elusive amid clashing incentives and priorities. But the multifaceted trade-offs demand reconciling to steer more responsible digital transformations in both industrialized and emerging economies.

Foremost, while expanding repair access promises cut waste disposal burdens, arguments bifurcate around how much marginal sustainability gains warrant risks to the much larger energy savings continuous technology advances unlock over time. for example, easing old iPhone maintenance likely modestly slows newer models' rapid 90% power efficiency improvements every generation. Similarly, restricting proprietary data access around vehicle telemetry risks dulling insights accelerating next-gen electric drivetrains with outsized decarbonization potential. Well-intentioned tinkering's conservation value directly trades off supporting pace and scale of innovation seen as essential addressing bigger environmental threats longer-term.

Balancing consumer rights against sector health tensions also run rife. Advocates argue unlocking repair documentation and spare parts availability defends customer agency over purchased products against corporate restrictions interfering arbitrarily post-sale. Yet companies counter opening unlimited access risks revenue cannibalizing counterfeit products while eroding delicate incentives around continuous high-risk R&D investments only recouped reliably through enough new model sales protected during limited exclusivity periods. They contend at-will tinkering needlessly jeopardizes larger innovation ecosystems supporting products themselves.

Developing countries additionally face sustainability arguments their surging living standards ride the wave of enlargening global innovation wealth created by planned obsolescence fuels - throwing such commercial engines in turmoil risks economic reversals most of all in emerging regions relying technology to uplift millions from deep poverty still today. Yet neglecting local circular economies repairing, recycling and remaking e-waste simultaneously relinquishes resources adding value at home while allowing uncontrolled environmental damage accumulating out of sight far from end-consumers distanced abroad.

Lastly the sheer diversity of interests defies singular outcomes at scale. While citizen hobbyists and trustees of archaic electronics gaining maintenance access makes intuitive sense supporting reuse cultures, the same diagnosis fails explaining highly precise medical equipment servicing needing institutionalized rigor where human lives are concerned, or autos employing advanced telemetric sensing safety requires manufacturer stewardship integrating. Difference of contexts and risk profiles involved must inform where self-service enhances rather than endangers outcomes.

In the backdrop looms growing urgency as sheer proliferation of internet-connected technologies explodes into food supply chains, infrastructure grids, furnishings and apparel guaranteeing embedded electronics transcend niche gadget accessories towards permeating everyday fabric nearly worldwide. Early infrastructure built around servicing principles today shapes entire regimes tomorrow. With sustainability, dignity, health and development all indivisibly linked to these deeply ethical decisions around repairability, may the coming years allow discourse bringing to light considerations easy to ignore when seen one-dimensionally rather than entwined. If mutual acknowledgment comes before lasting understanding, humanity still has hope treading challenging questions of limits arising digital abundance together, carefully.

5.2 Developing Countries Poised to Lead in Repair-Oriented Policies

While industrialized economies historically drove global consumption and innovation patterns, developing regions now stand poised to pioneer more sustainable electronics repair, reuse, and recycling models ameliorating externalized waste dumping while uplifting marginalized workers. Motivated by necessity and

economic pragmatism, poorer nations for years sustained vast informal sectors refurbishing technology castoffs to extend access and affordability amidst scarce domestic purchasing power. By transforming such ingenuity into formalized, ethical enterprises centered on longevity, developing countries redirect waste from inevitable byproduct toward circular engines uplifting millions from poverty.

In contrast to planned obsolescence regimes fueled by elite consumerism and disposable incomes abroad, innovations around reuse flourish out of grassroots necessity across Africa, Latin America and South Asia. Bootstrapping entrepreneurs building businesses salvaging discarded electronics react to acute awareness of externalities around dumping from the developed world. violating both environmental sanctity and economic sovereignty. Establishing ethical repair value chains thereby proves a political act - an assertion of resource agency and mobility bridging divides. “Appropriate technology” labs making medical equipment affordable sustain entire public health systems otherwise relying overseas charity continually.

The sheer volumes of waste imposed also foster scaling breadth. Africa alone imports up to 10 million tons of secondhand electronics like PCs yearly, of which anywhere from 30-75% quickly become e-waste. India piles 120 million smartphones in people’s houses going unused every two years. Sheer surplus base materials drive systems supporting legions of specialist refurbishers, dismantlers, and parts harvesters even under legal gray areas - testing ground for potential formalization. Enormous informal sectors readily prove viability around maintenance and reuse even absent policy reforms easing restrictions by global brands.

Positive precedents now emerge as governments recognize repair ecosystems’ developmental power. South Africa recently began accrediting informal e-waste workers while funding cooperatives gaining tools and safety certifications qualifying higher value contracts refurbishing public sector equipment bought locally. Rwanda pioneered East Africa’s first e-waste recycling plant while 3D printing lab leverages community plastic waste improving medical access. Impact investors also help township enterprises sell refurbished electronics to second owners. Such legal recognition helps hitherto marginalized workers claim dignified environmental stewardship roles.

With mushrooming youth demographics from India to Kenya standing to gain most from technological transformations, governments increasingly endorse localization, transparency and interoperability as sustainability multipliers benefiting societies over profit-centric planned obsolescence. Right to repair legislation now sees discussion from Delhi to Nairobi capitals given domestic waste and unemployment pressures. Even nations like Ethiopia and Bangladesh where under half the population owns smartphones develop circular economy roadmaps to uplift disadvantaged citizens through repair services and remanufacturing rather than raw exports.

Poised to reap dividends as both labor-rich societies and dumping grounds externalities imposed upon, developing countries bear outsized stakes forging new narratives around e-waste from blight to feedstock fueling locally rooted industries. Much as off-grid solar and mobile money innovations uniquely suited emerging contexts, sustainability here springs not from elite choice but indigenous enterprise addressing acute needs creatively. The case for policies fostering domestic repair ecosystems rests on multiplying social benefits long before exacting environmental costs are tabulated far away. This time the Global South leads consciences recognizing true value - and seeking it not where convenience hides unseen out of view abroad, but nearest where vulnerability still resides at home.

5.3 Call for Collaborative Action Across Policy, Business, and Civil Society

With e-waste expanding exponentially and alarms sounding on destructive dumping burdens inflicting developing regions, the singular clarity around spiraling consumption demands cooperative interventions realigning incentives benefiting business and society. Rather than penalize innovation ecosystems powering prosperity for billions, the solution requires holistic collaboration enshrining principles of transparency, interoperability and accountability reinforcing ethical value chains benefiting both profits and people sustainably.

Calls for collaborative action acknowledge corporations play indispensable roles democratizing access that alleviates inequality. Technology progress stands among humanity's highest moral priorities uplifting marginalized populations through opportunities otherwise unfathomable. Any reforms threatening long term innovation risk unintended losses nullifying harder to quantify sustainability gains around annoting particular waste streams. Industry and policymakers must strengthen shared trust balancing complex tradeoffs. The first priority demands jointly defining normative boundaries on reasonable product access given context. While easements ensuring basic repairability and safety seem straightforward for most consumer electronics, far greater cautions are warranted around highly precise medical equipment or automotive systems where slipups risks lives directly. Those boundaries appear vastly different for tractors farmers own than rented scooters needing operational oversight. Rather than one-size-fits all right to repair regimes, tiered sector-specific charters negotiation by industry and user groups promises more nuance aligning responsibilities curbing perceived excesses transparently.

Next arises strengthening reverse logistics and infrastructure catching usable materials businesses create but don't yet internalize recycling costs for along entire life cycles. Manufacturers could collaborate with municipal collectors routing batches of discarded electronics to accredited refurbishers for triaging and reselling usable units at lower cost brackets while harvesting recyclable commodities sustainably. Such hub-and-spoke systems embedded locally keeps value circulating regionally compared externalized waste dumping overseas - formalizing informal sectors incorporating environmental costs benefiting all nodes. Smarter pricing and responsibility models also show promise realigning business models nurturing circularity. Products-as-services leasing enterprises could let brands retain ownership optimizing reuse and maintenance directly. Packaging bans and recovery targets enacted across dozens of countries pushes scale pooling recycled plastic and glass. Takeback mandates make companies responsible discarded stock they produce rather than municipalities, incentivizing durability. And certified repair provider networks give independent shops access benefiting hand consumers while creators still steer quality assurance.

Motivating lasting change ultimately hinges on societies and governments sending clearer signals prioritizing sustainability and equitability long run. With rising calls for moratoriums on planned obsolescence business models by 2030, the issue commands global attention from World Economic Forum dialogs to dedicated working groups under United Nations Environment Programme umbrella focused on responsible e-waste management nuanced by each nation's constraints. Rather than fragmented niche advocacy, the vision beckons unified movements educate consumers, empower entrepreneurs and enact policies in step steering industries toward circularity.

The window for leadership stands open but narrow. Those taking initiative now demonstrate commitment benefiting disproportionately as best practices crystallize rapidly into new global standards. The costs of inaction loom even larger as electronics permeate infrastructure integrities once considered mundane - from roadways embedded with sensors to immersive metaverse environments lived inside. By seizing

today's opening moments, corporations, activists and regulators together reshape trajectories determining how humanity interacts with the very technological fabric increasingly mediating essential functions of life.

REFERENCES

[1] Kornack, D. R., & Rakić, P. (2001, December 7). Cell Proliferation Without Neurogenesis in Adult Primate Neocortex. Science. https://doi.org/10.1126/science.1065467
[2] Manfredi, R. (2023, October 20). The Rise of State Laws Restricting Foreign Entities from Acquiring Property: Another Front in U.S.-China Tensions and the Constitutional Challenge of Florida SB 264 in Shen v. Simpson. Gibson Dunn. https://www.gibsondunn.com/rise-of-state-laws-restricting-foreign-entities-from-acquiring-property-another-front-in-us-china-tensions/
[3] Chamberlain, E. (2024, April 10). Right to Repair Progress. iFixit. https://www.ifixit.com/right-to-repair-progress
[4] Turiceanu, V. (2024, January 9). What You Need To Know About the Right To Repair Act in 2024. Built In. https://builtin.com/articles/right-to-repair-act
[5] George, A. S., George, A. H., Baskar, T., & Sujatha, V. (2023, December 25). The Rise of Hyperautomation: A New Frontier for Business Process Automation. puirj.com. https://doi.org/10.5281/zenodo.10403036
[6] Calma, J. (2020, July 2). Humans left behind a record amount of e-waste in 2019. The Verge. https://www.theverge.com/21309776/record-amount-ewaste-2019-global-report-environment-health
[7] F. A. (2023, April 21). The Environmental Impact of Digitalisation: What's Your Take on Sustainable Technology? | FDM Group. FDM Group. https://www.fdmgroup.com/news-insights/environmental-impact-of-digitalisation/
[8] Eco-Friendly Technology: Innovations for a Sustainable Planet – GadgetGlint. (n.d.). https://gadgetglint.com/eco-friendly-technology-innovations-for-a-sustainable-planet/
[9] Ascension, A. (2023, January 9). 10 Environmental Impacts of Electronic Waste - Environment Go! Environment Go! https://environmentgo.com/environmental-impacts-of-electronic-waste/
[10] Bencke, G. (n.d.). E-Waste - The Dark Side of Tech | torvius.com. torvius.com. https://torvius.com/e-waste-the-dark-side-of-tech/
[11] How Do Electronics Affect The Environment | CitizenSide. (2023, December 31). CitizenSide. https://citizenside.com/technology/how-do-electronics-affect-the-environment/